Streamlining Shipyard Rigging Analysis
Integrated Lifting Lug Testing
Ship Production Process Technology Panel

September 2010

Streamlining Shipyard Rigging Analysis

- The bulk of this research related to how to most efficiently and accurately engineer the lifts of large ship structure.
  - ➢ Finite element detail required and constraints to use
  - ➢ Accuracy of classical calculations with different assumed structural effectiveness of main members.
  - ➢ Estimation of dynamic loads lifted blocks see.

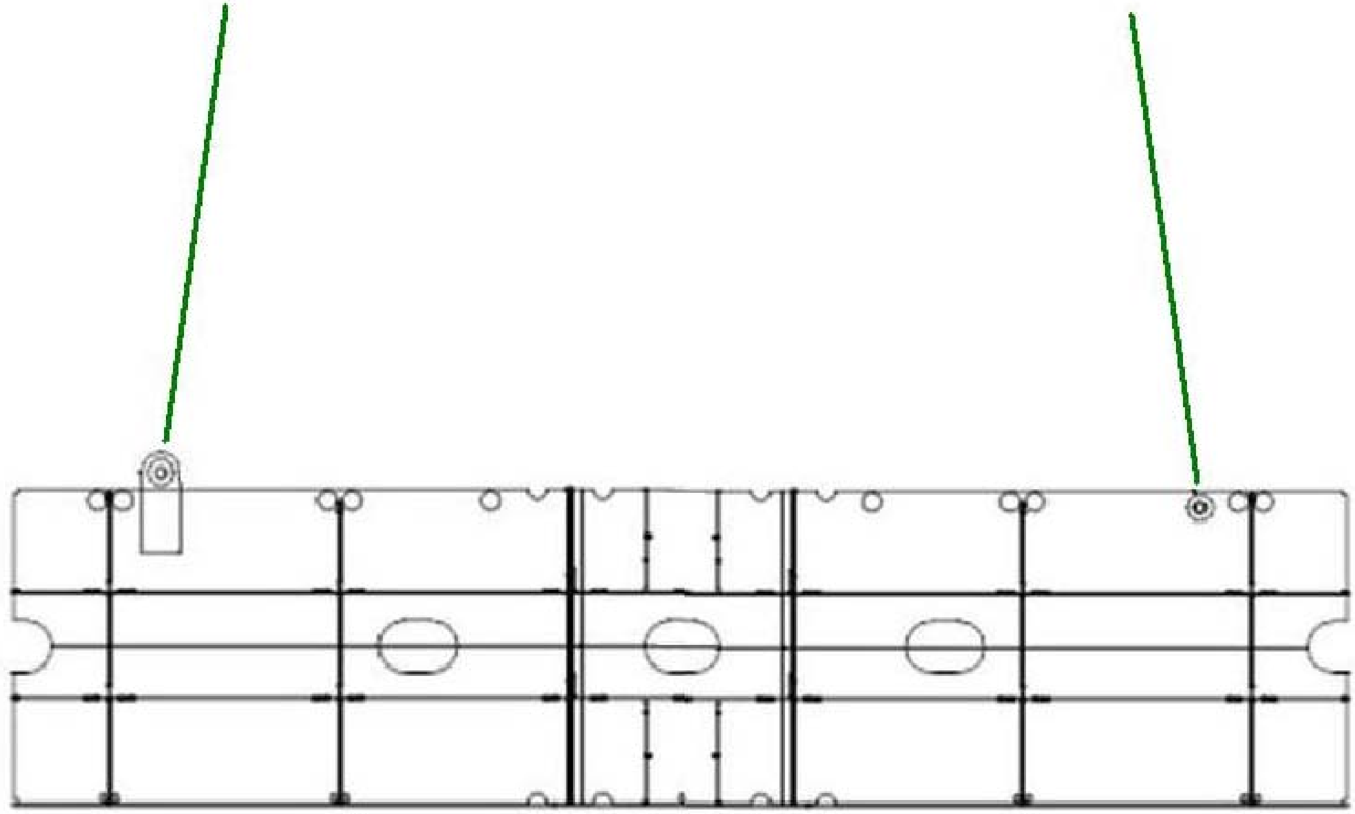
- Recent efforts that will be presented today relate to rigging attachments in thin plate material.

Traditional Rigging Attachment

- Traditional padeye used during Ship construction are:
  - Welded on
  - Cut off
  - Repair Required

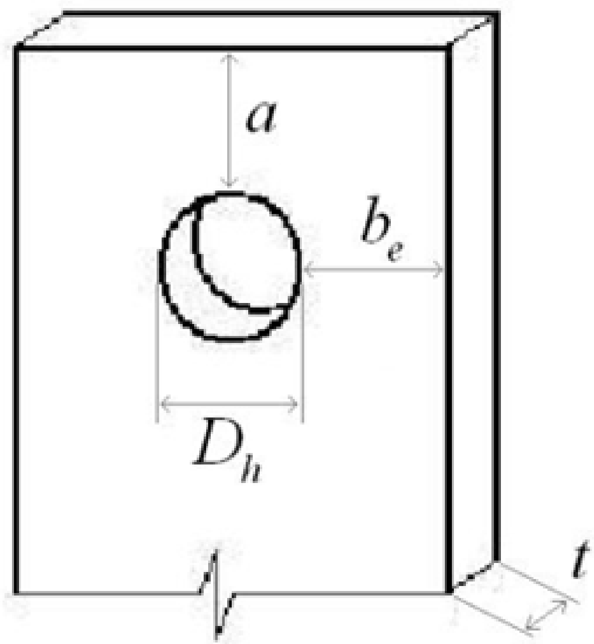
Integrated Lifting Lug

- The replacement of traditional padeye with lifting holes integrated into ship structure will result in savings from the reduction of processes required.



Pin Connection Equations

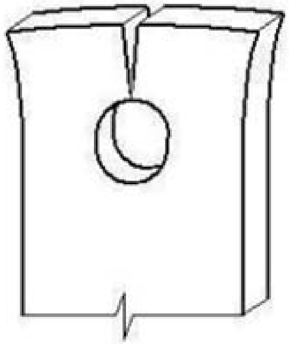
- Empirical Equations
  - Based on 106 Destructive tests in 1938
  - Adopted by ASME Below-The-Hook Standard for Pin Connections
- *"Because of the early local yielding and associated stress redistribution, mathematical formulas for the maximum local stresses based on the assumption of elastic behavior have doubtful utility in the actual design of pin connection steel plates"* --Johnston 1938
- Destructive test provide the most information about failure loads for these devices.



- Similarly, linear FEA cannot be used to predict ultimate failure load.

Pin Connection Equations

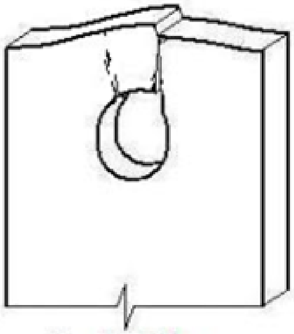
- Fracture



Fracture Strength

$$P_b = \frac{F_u D_h t}{1.2 N_d}\left[1.13\left(\frac{a}{D_h}\right) + \frac{0.92\left(\frac{b_e}{D_h}\right)}{1+\left(\frac{b_e}{D_h}\right)}\right]$$

- Shear

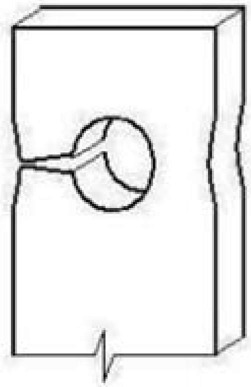


Double Plane
Shear Strength

$$P_v = \frac{0.7 F_u t}{1.2 N_d} 2\left[a + \frac{D_h}{2}\left(1-\cos(45)\right)\right]$$

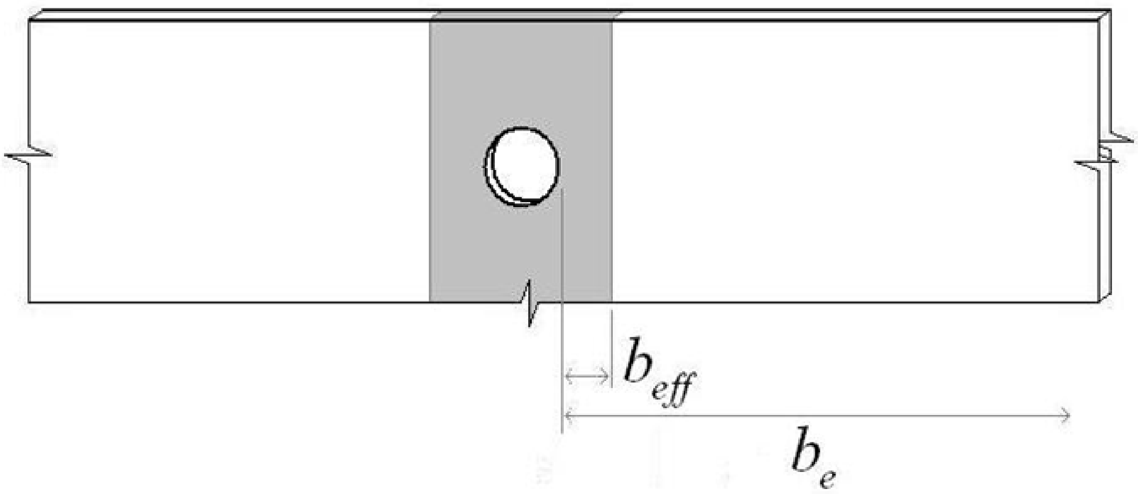
Pin Connection Equations

- Tension



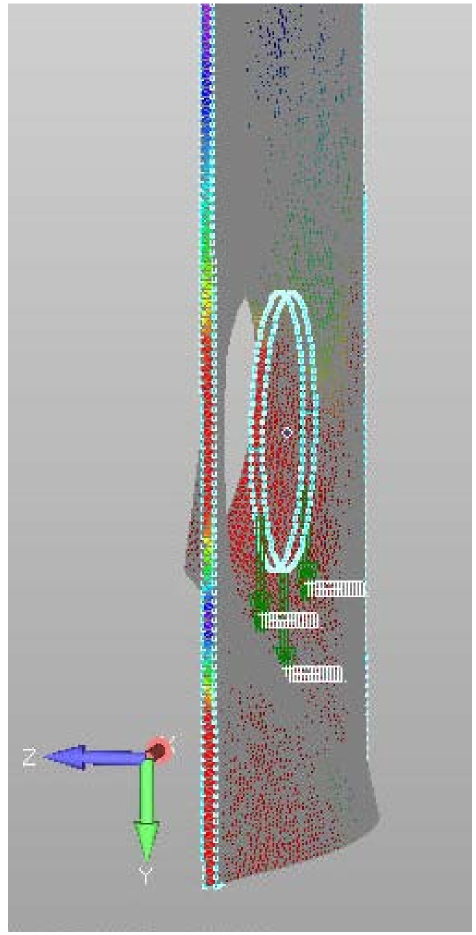
Tension Strength

$$P_t = \frac{F_u t}{1.2N_d}\left[2b_{eff}\right]$$ most importantly with $b_{eff} \leq 4t$



Dishing, Curling, Tripping

- Dishing is the local instability of the plate material above the hole
  - ➢ Linear FEA estimation significantly effected by non-linear strain redistribution



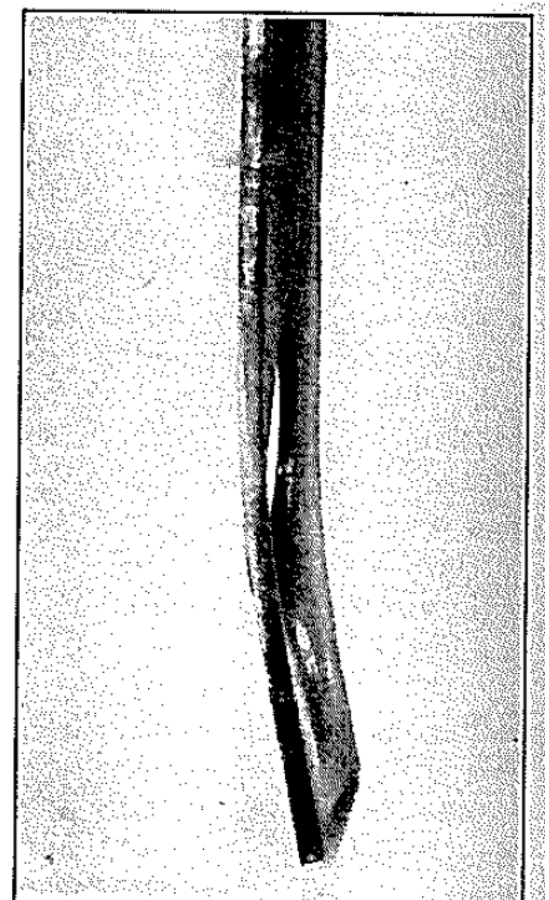


FIG. 6.—SHAPE OF TEST PIECE AFTER FAILURE BY "DISHING"

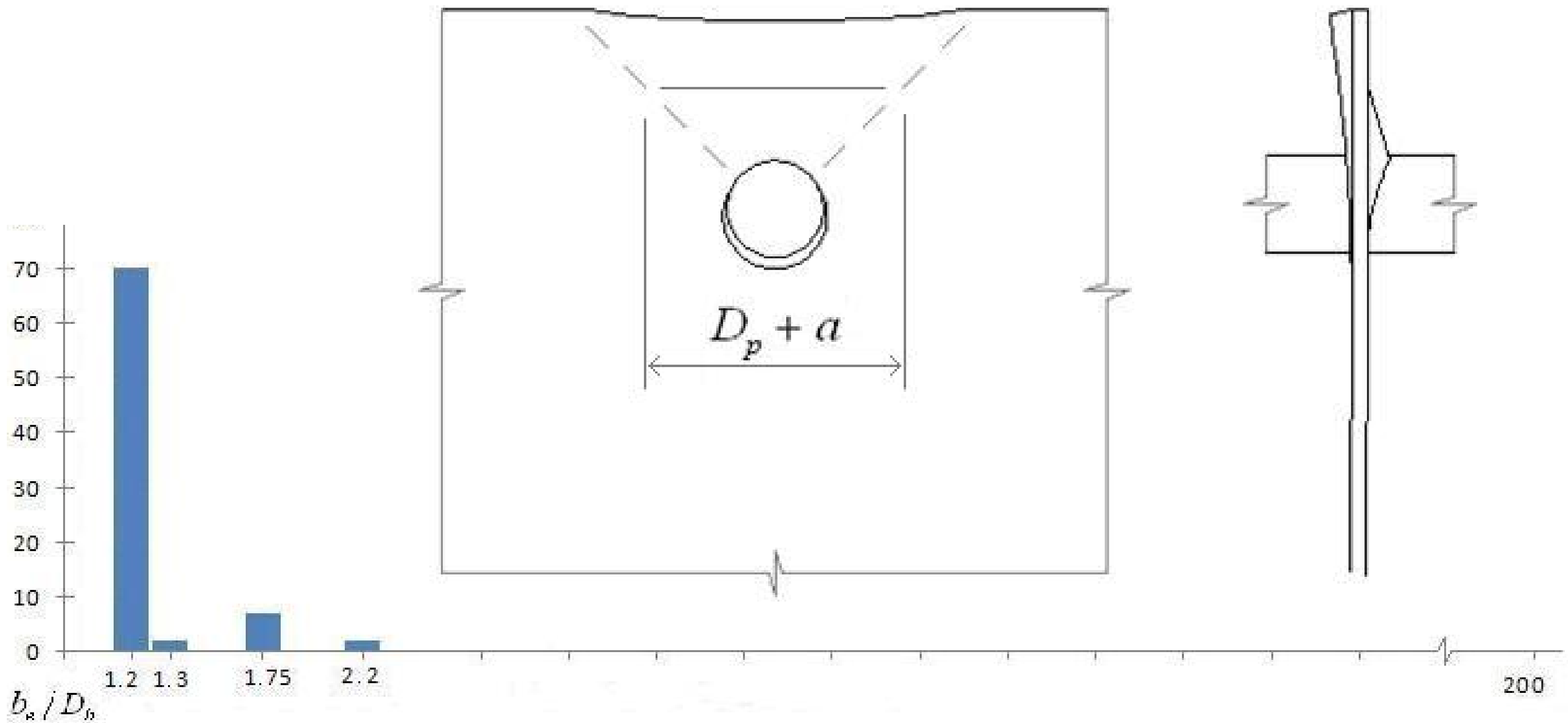
Figure 6 from Johnston, B.G. (1938) "Pin Connected Plate Links", Transactions of A.S.C.E. pp. 461-483

Dishing

- Johnston created empirical equations for dishing which could be considered reasonably accurate for his range of testing.
  - $$s_{bt} = 20 + 315\left(\frac{t}{D_h}\right) + 75\left(\frac{tb_e}{D_h^{\ 2}}\right) + 20\left(\frac{a}{D_h}\right) - 20\left(\frac{a}{D_h}\right)^2$$
  - With: $$0.3 < \left(\frac{a}{D_h}\right) < 1.2$$
    $$0 < \left(\frac{D_h - D_p}{D_h}\right) < 0.07$$
    $$0.5 < \left(\frac{b_e}{D_h}\right) > 1.2$$
  - Biggest term for dishing resistance in thickness, t
  - Second biggest term in width, b_e
  - Curiously, the more material above the hole there is, a the sooner dishing will occur, possibly with negative values for deep set holes

Dishing

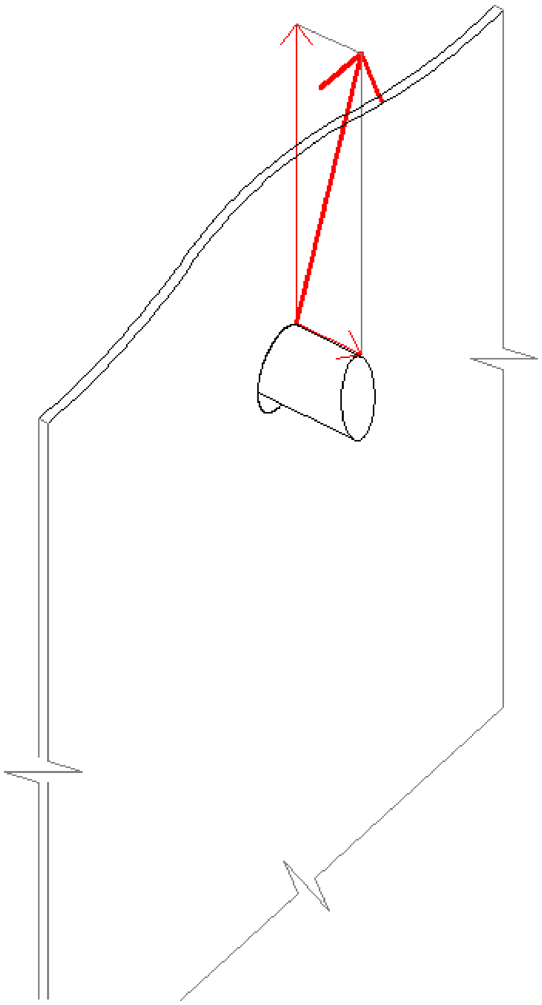
- Wide plate dishing experiments have not been done.
  - How wide is wide?
  - Deurr(2006) has proposed pin diameter plus height is effective width $D_p + a$
  - Empirical data has not been collected for wide plates



Dishing

- To use integrated lifting lugs in a production environment other factors need to be considered.
- Side loads should in theory reduce the plates resistance to dishing failure.

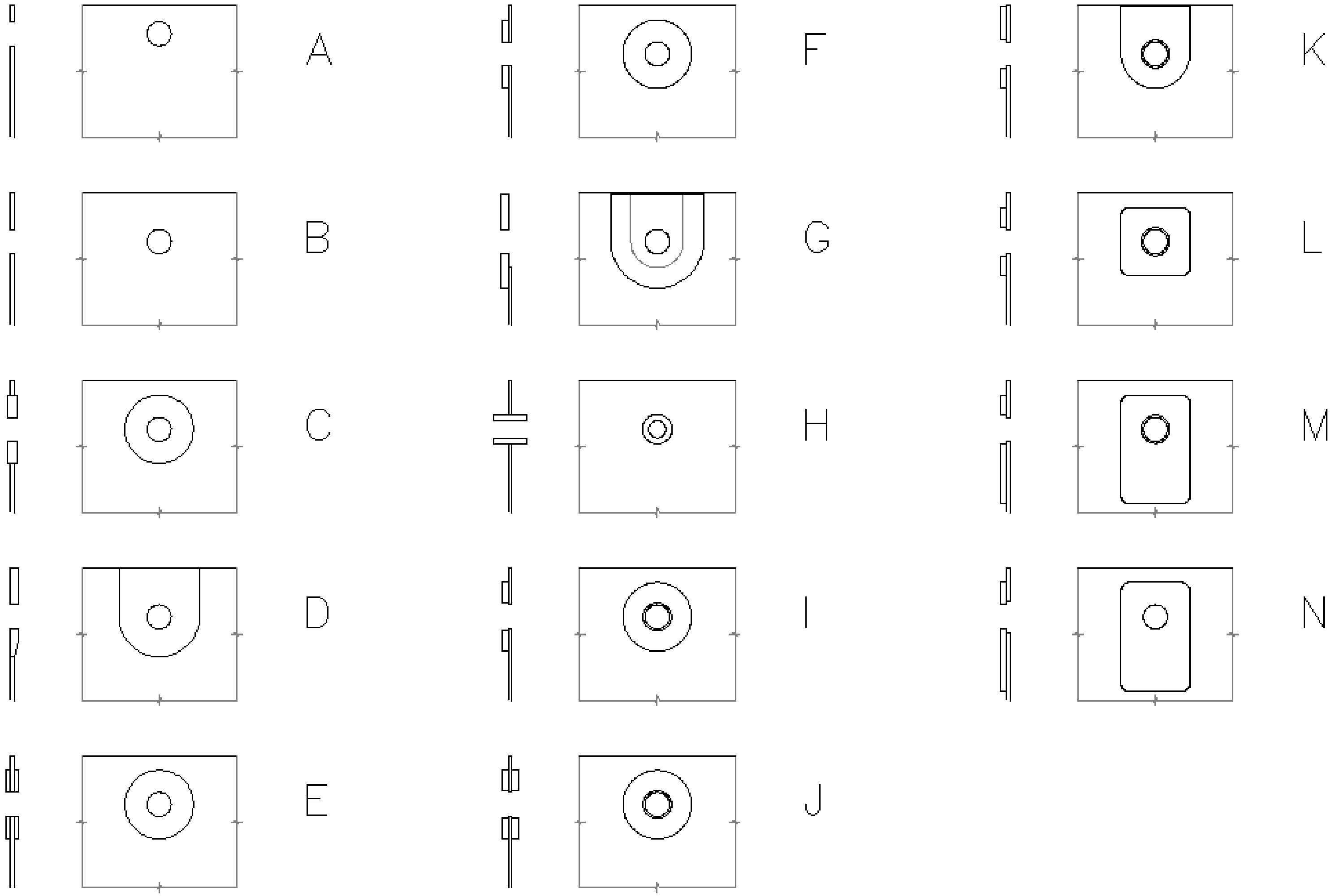
  - No data has ever been published about early dishing initiation from side loads.



Problem Statement

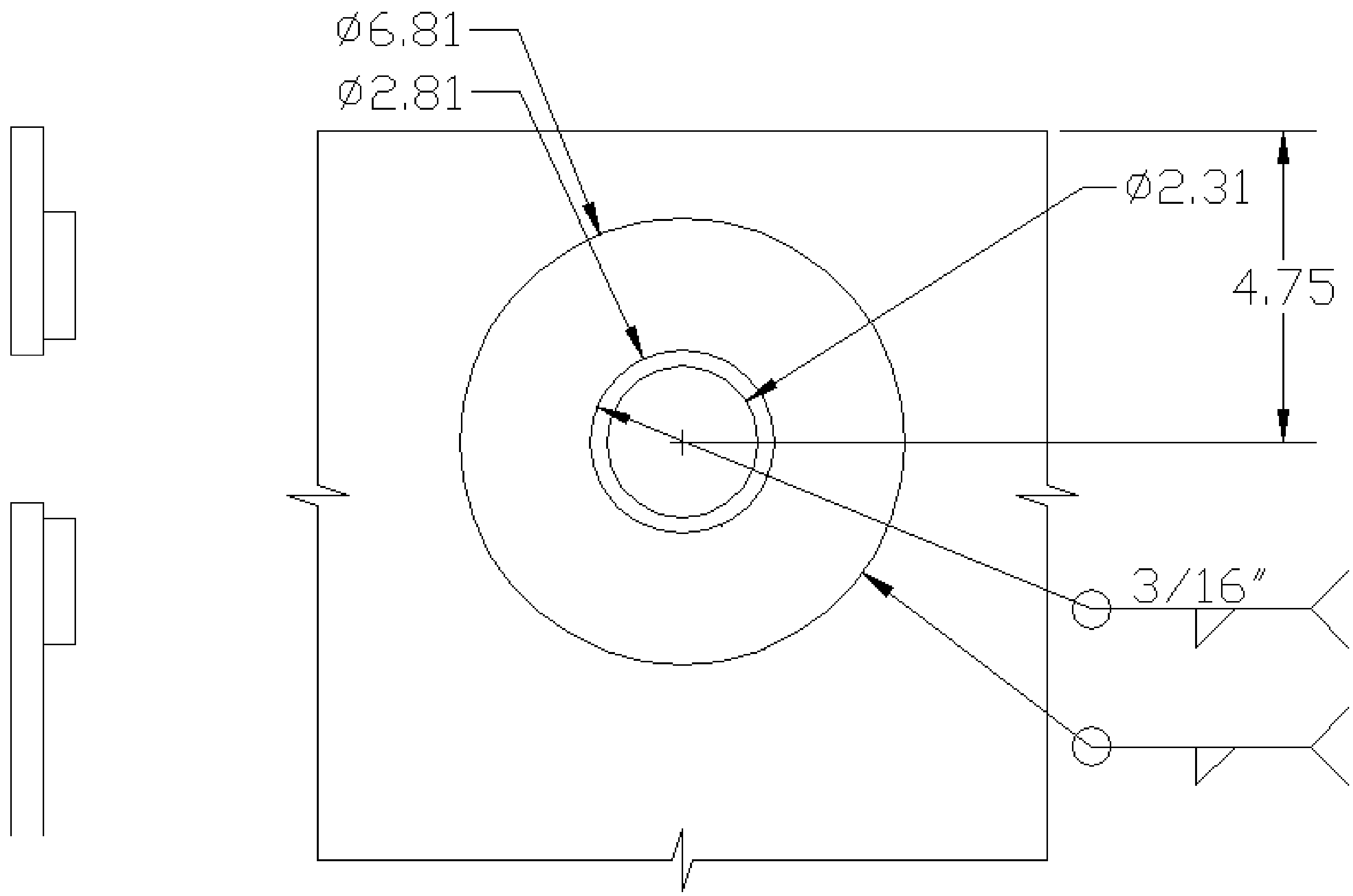
- How can we best adopt integrated lifting points into a build strategy?
- How well do empirical dishing equations work outside their developed range?
- What effects will side loads have on pin connections subject to dishing?
- What types of local stiffening can be added to prevent or forestall dishing instability?
- What type of stiffening is most effective?

Design Possibilities



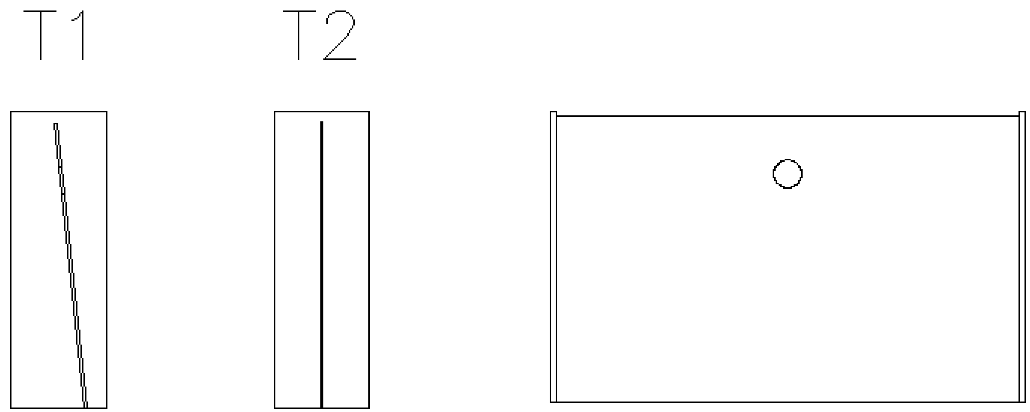
Design Possibilities

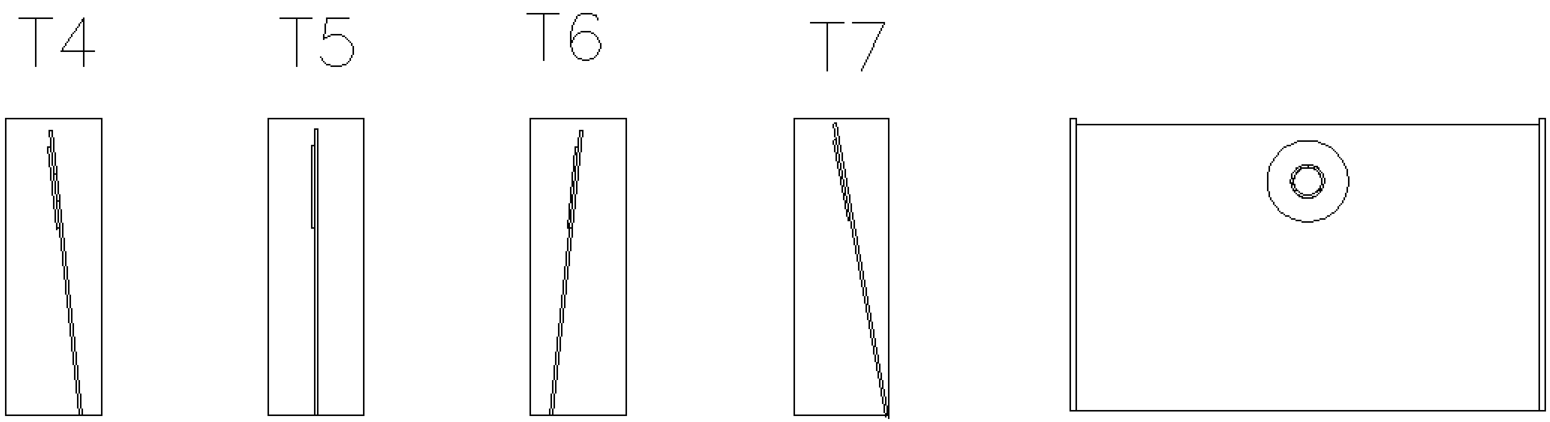
- Baseline “Standard” Lap-on Offset Doubler Plate



Tested Types

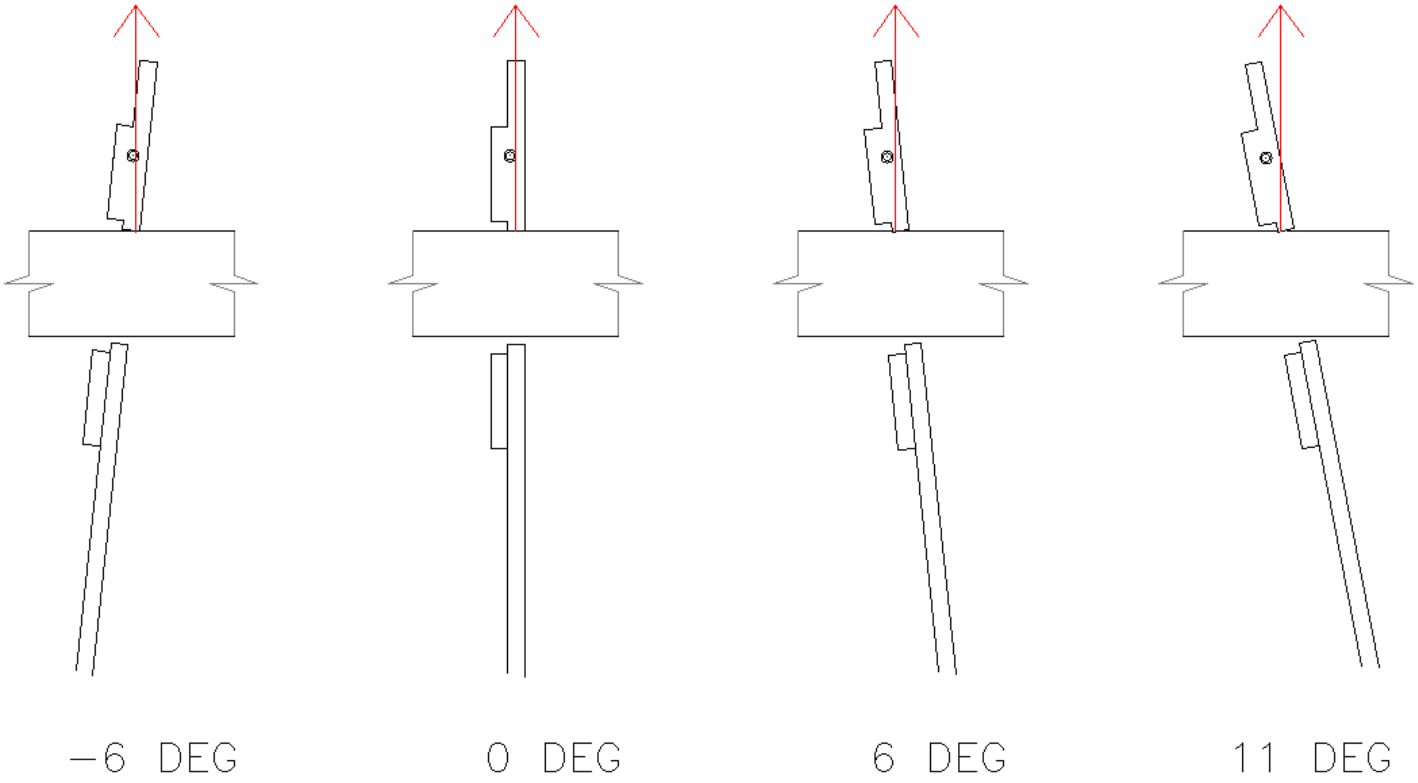
- T2 Wide pin connection test allows comparison to historical data set
- T1 Side load reduction
- T4, T5, T6, T7, tests on baseline lap-on doubler at different angles





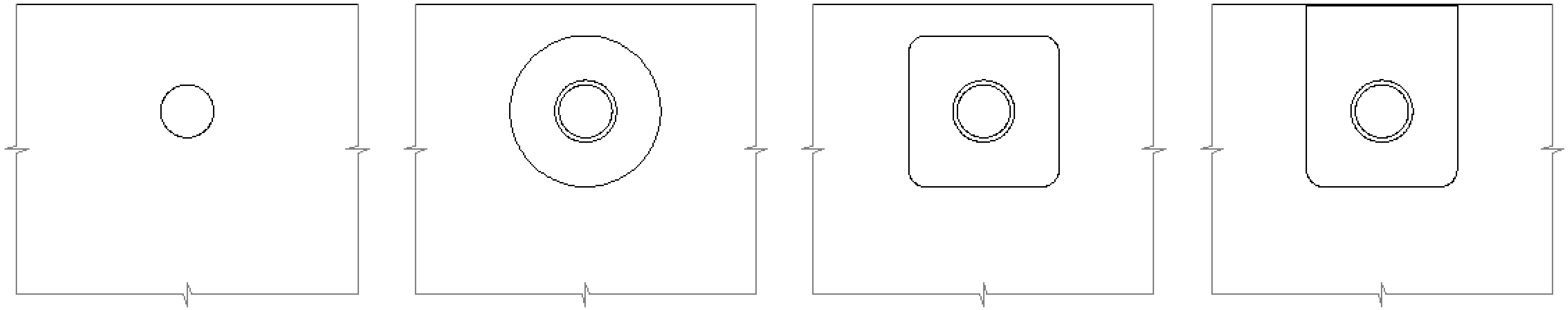
Side Loads

- Asymmetric pin connections
  - Not all side loads are the same.



Tested Types

- Test were preformed on four basic types of lifting lugs with in plane and out of plane loads
  - Circular Doubler
    - Typical boss plate shape
  - Square Doubler
    - May stiffen top edge better with longer weld line
  - Rectangular Doubler
    - Production friendly as less welding
  - Un-stiffened Hole
    - Provided baseline to compare to historical data set



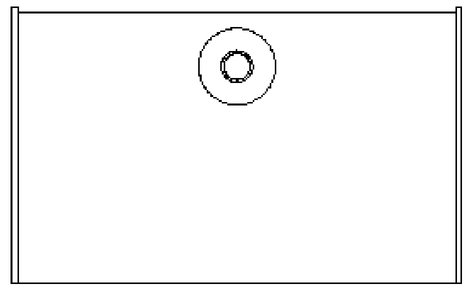
Tested Types

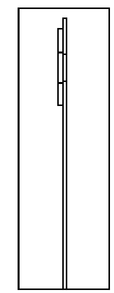
- T9, T10 were tests to determine if different shape doubler would significantly effect failure strength
- T3, T8 were tests with thick doublers plates that brought dishing section close to observed limit state

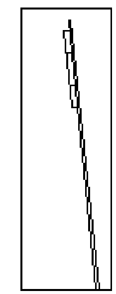
$$\frac{a}{t}\frac{D_h}{D_p} < 0.19\sqrt{\frac{E}{F_y}}$$

T3

T8

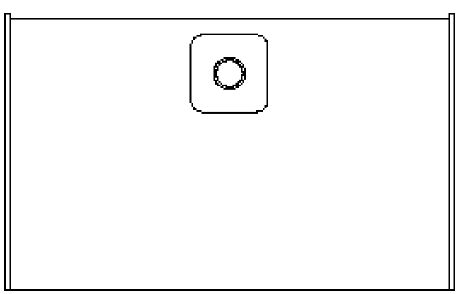


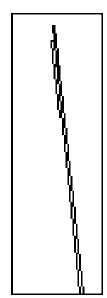


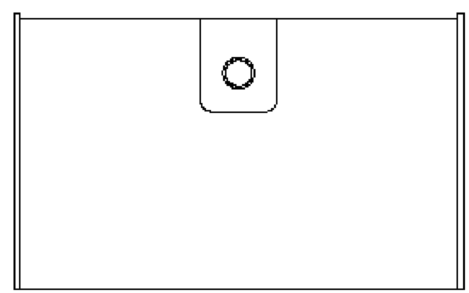


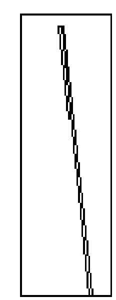
T9

T10



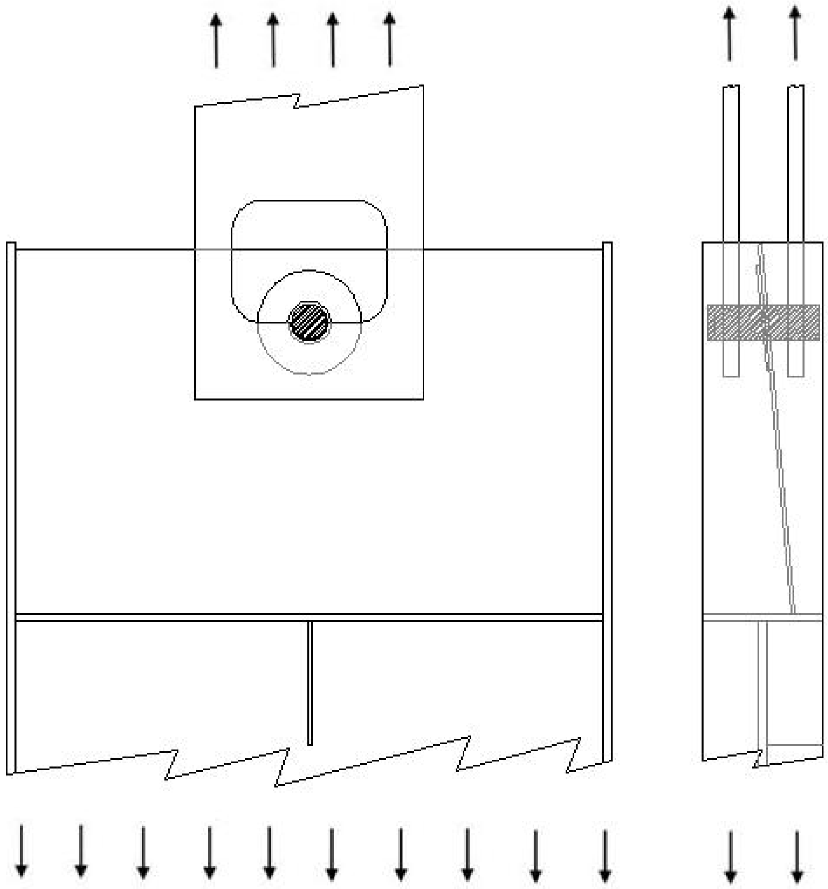


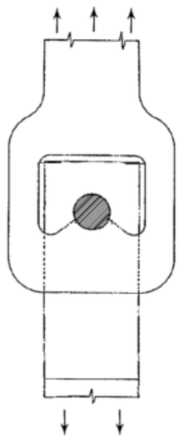




Tested Types

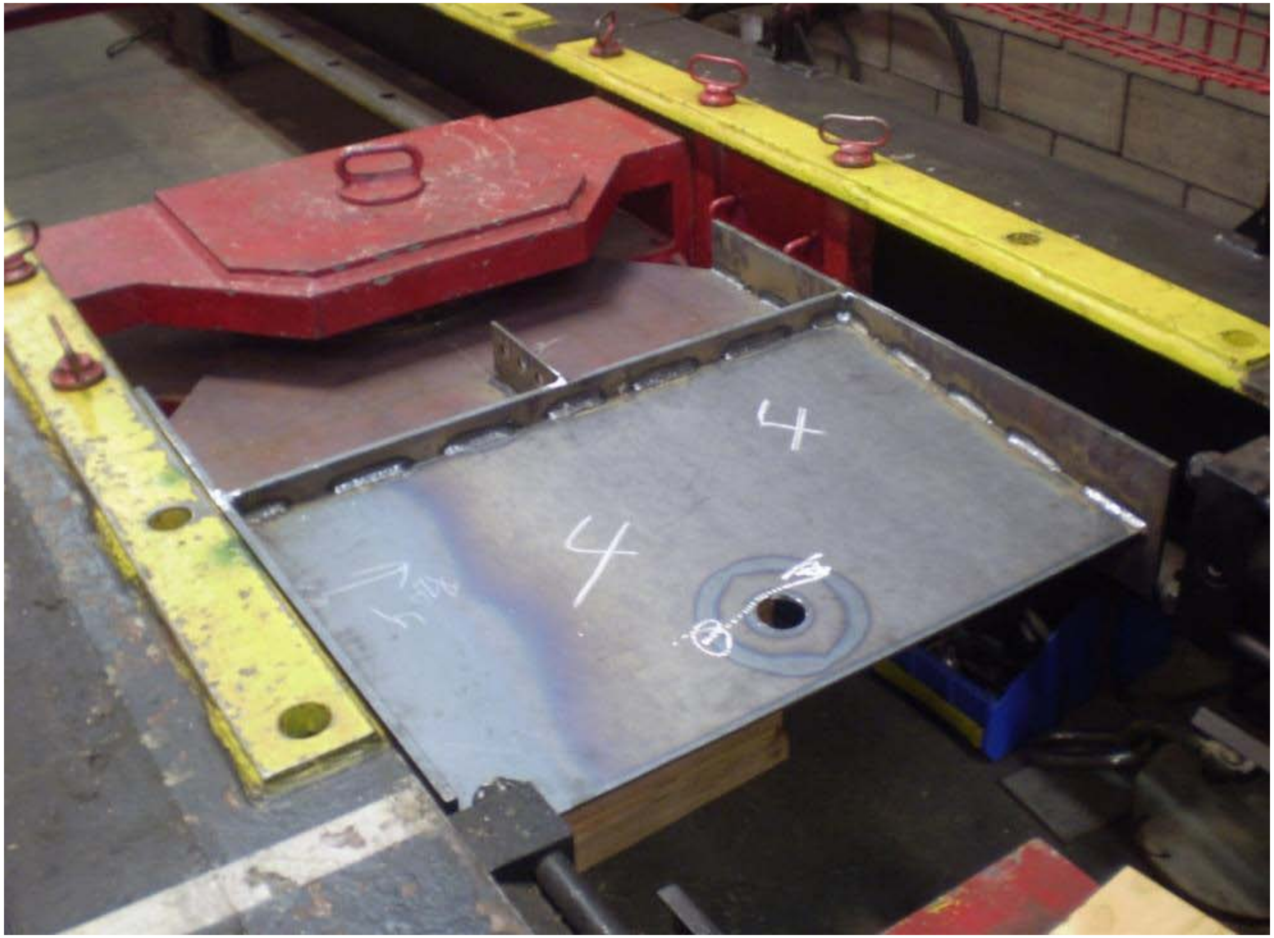
- Test apparatus was heavily influenced by Johnston's 1938 arrangement.





Test Setup

- Test plate T4 blocked up into position



Test Results

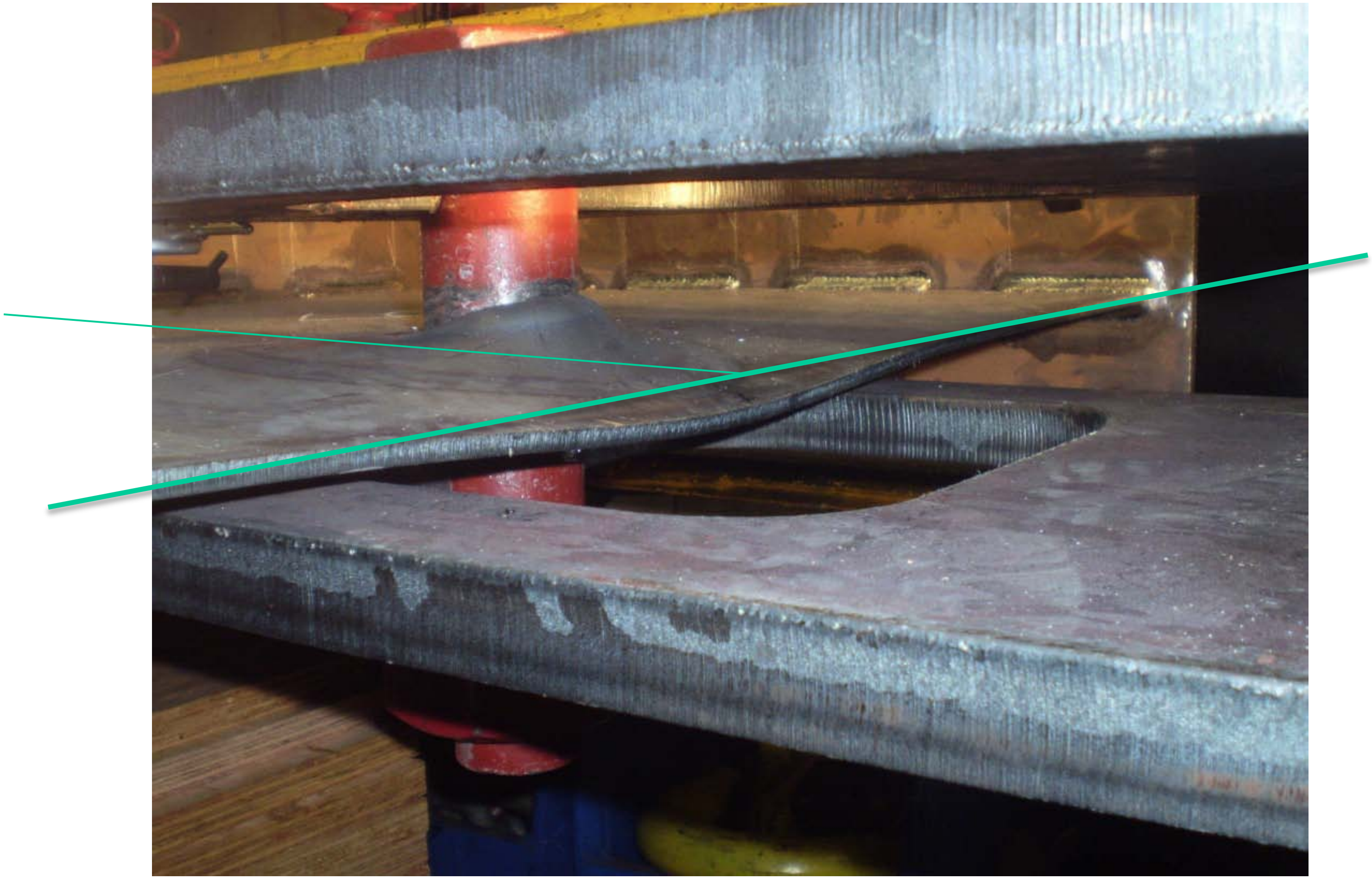
- Test Plate T4 after ultimate load

Test Results

- Test plate T5 after ultimate load, heavy dishing evident

Results

- Test plate T5 after ultimate load, heavy dishing evident

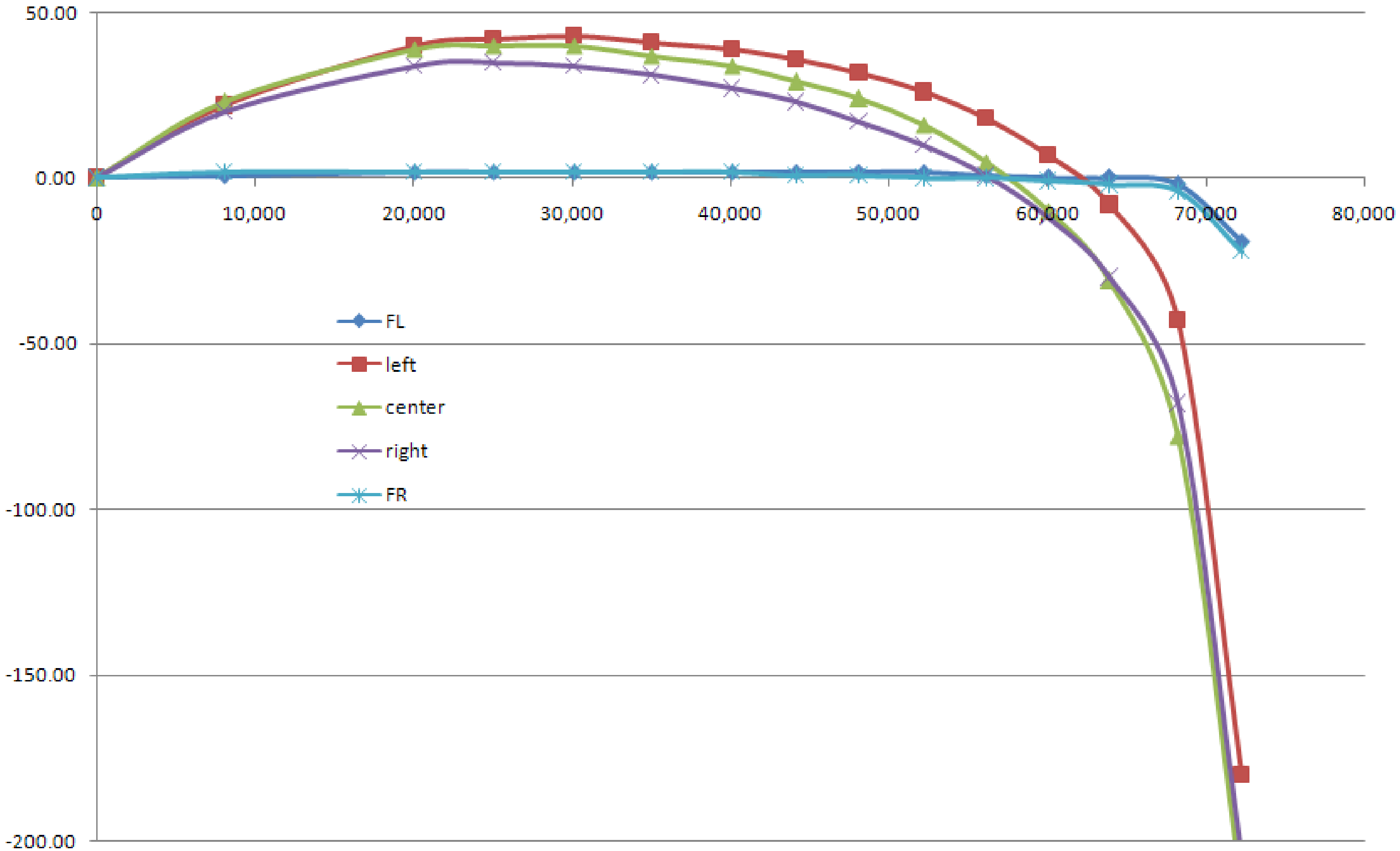


Test Results

- Test plate T5 showing dishing measurement dial indicators

Test Results

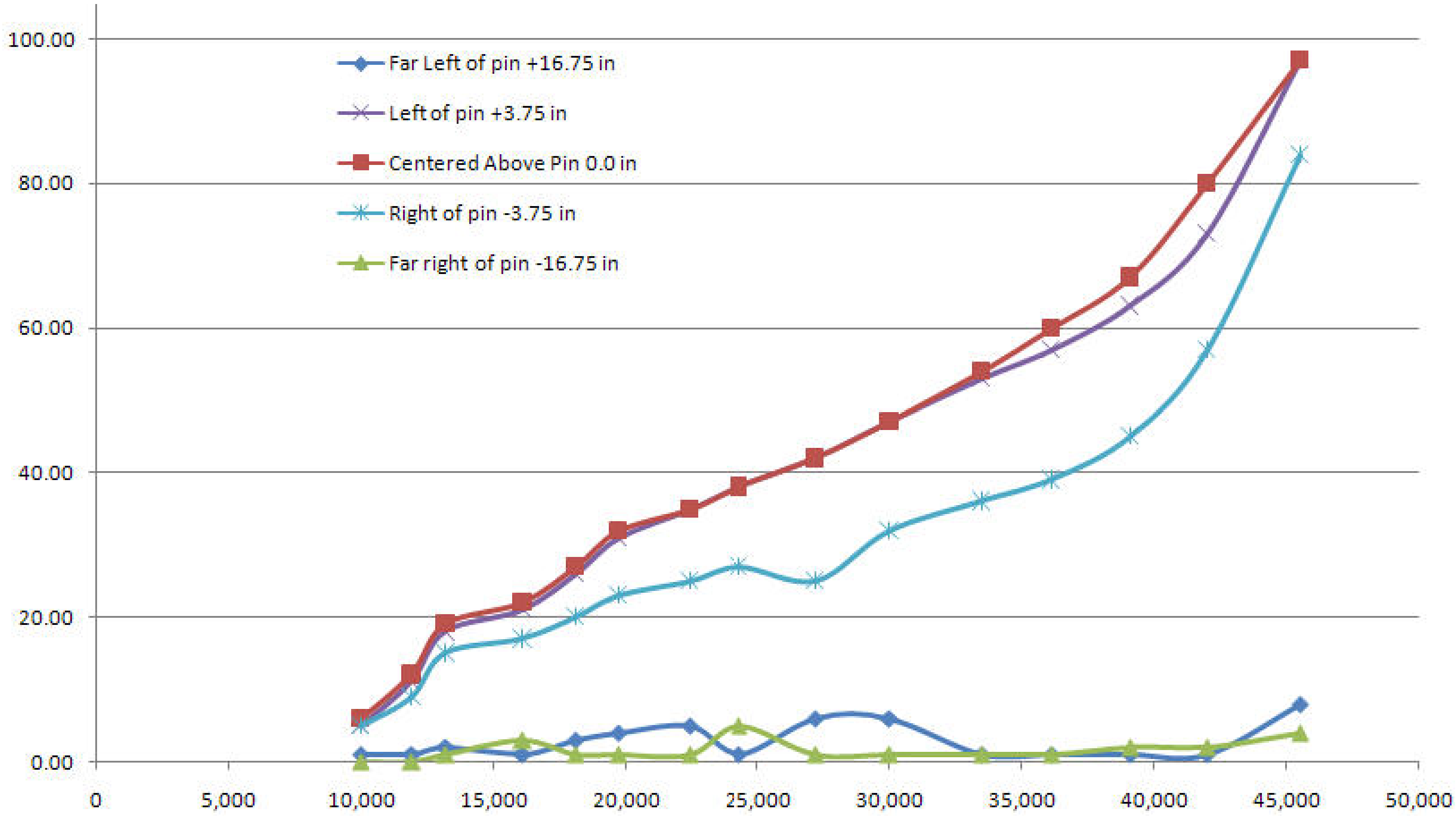
- Test plate T5 dishing deflection



GENERAL DYNAMICS
nassco

Test Results

- Test plate T2 dishing deflection



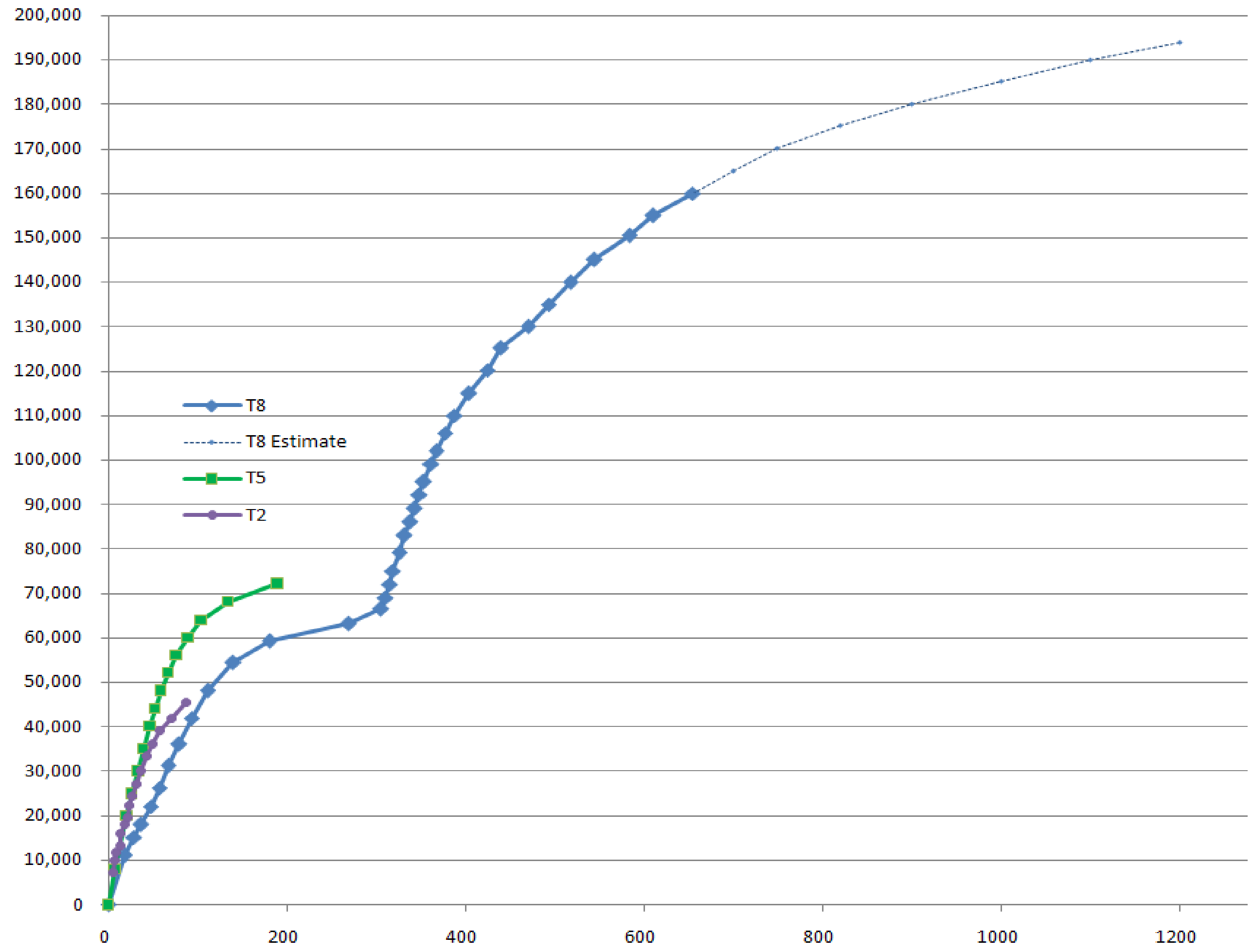
GENERAL DYNAMICS
NASSCO

Test Results

- Pin travel was measured by proxy
  - Dial indicator measured test frame to loading fork separation

Test Results

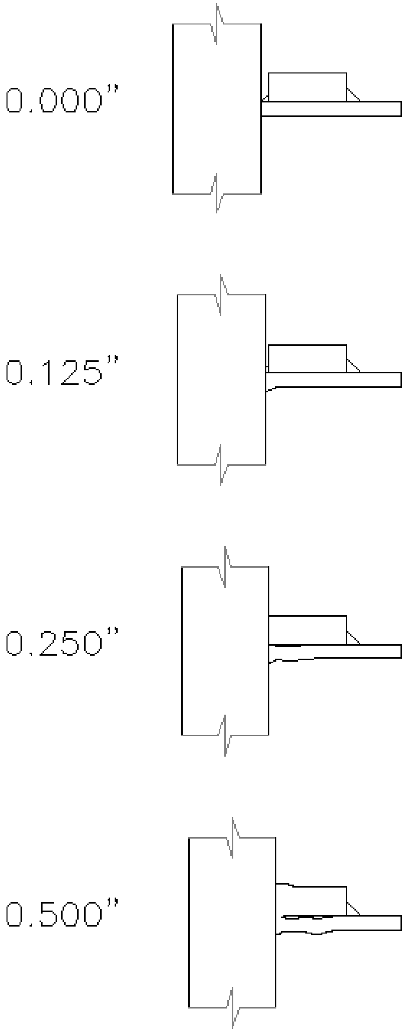
- Load vs. Deflection



GENERAL DYNAMICS
NASSCO

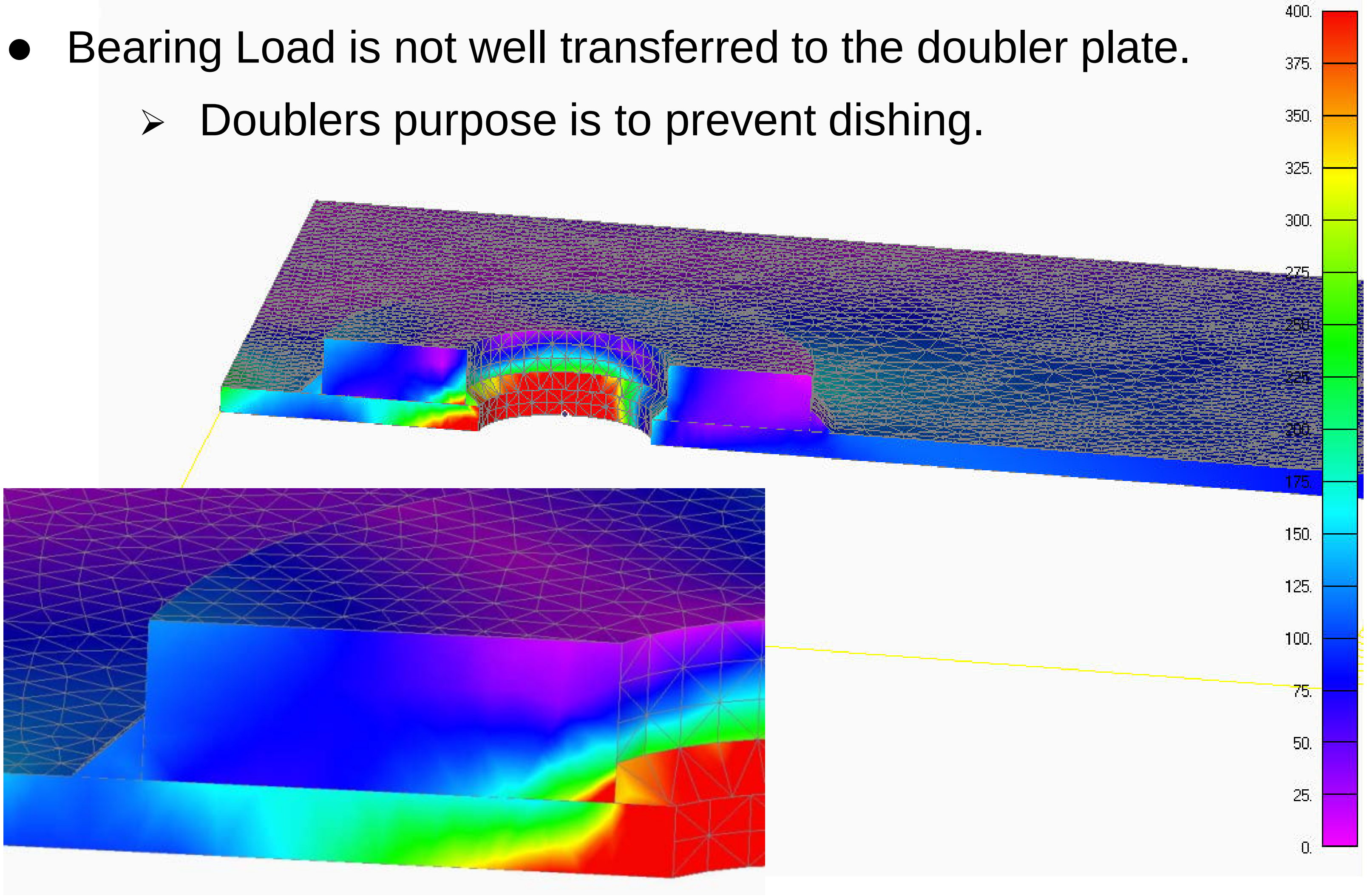
Test Results

- Why the double yield hump in test specimen T8?
  - As pin bore into thin plate initial failure occurred at a similar load as the other specimen.
  - After 250 thousands pin travel contact was made with the larger stiffer doubler.
    - Both plates shared the load.



Test Results

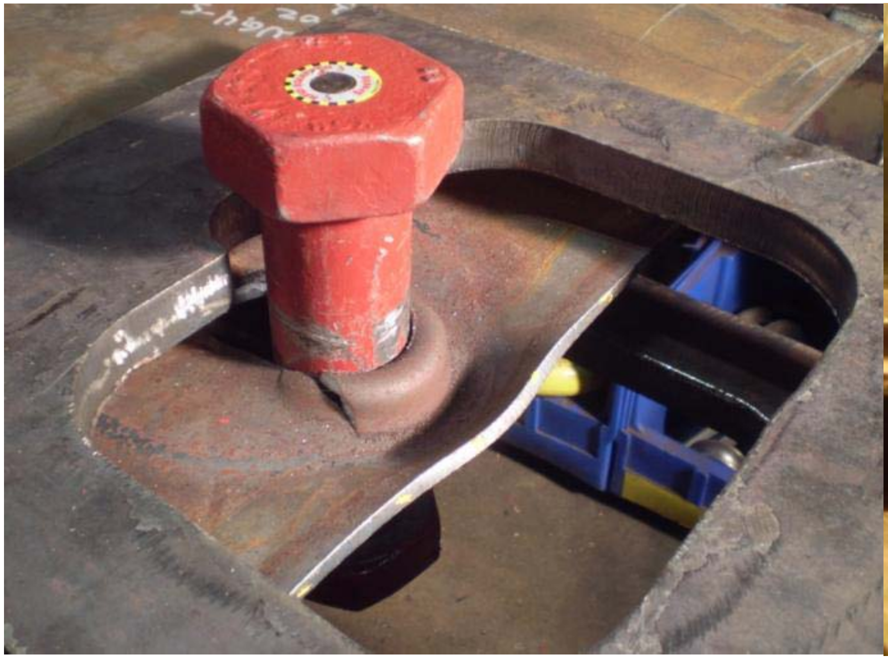
- Bearing Load is not well transferred to the doubler plate.
  - Doublers purpose is to prevent dishing.



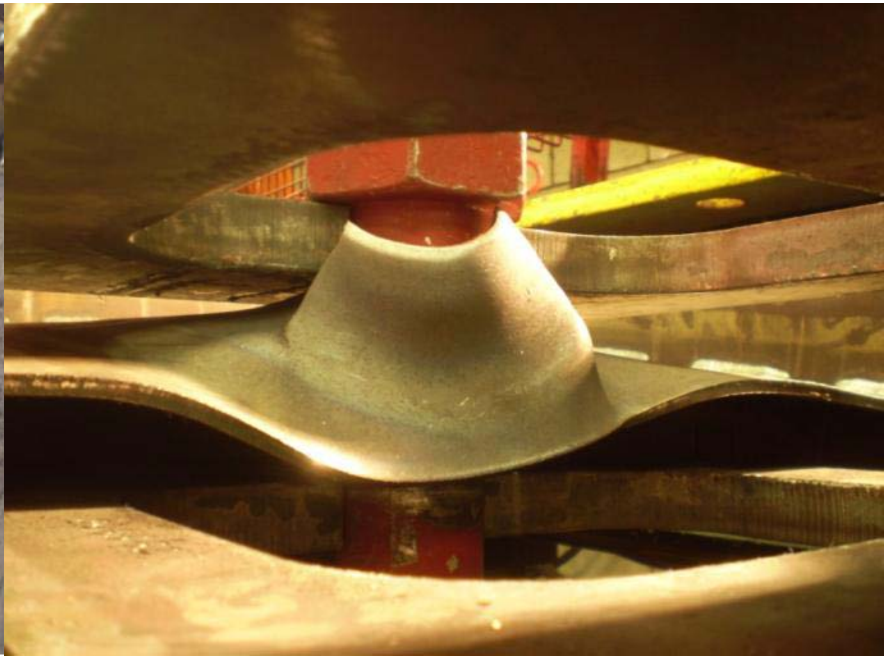
Test Results

- Side loads caused dishing failure with thick doubler,
- In plane loads caused folding of the material, but was not similar to all other dishing observed.

0 Degrees



6 Degrees



GENERAL DYNAMICS
NASSCO

Test Results

- How do results compare to ASME/Johnston/Duerr failure estimates?
  - T2 is only sample that can be compared directly

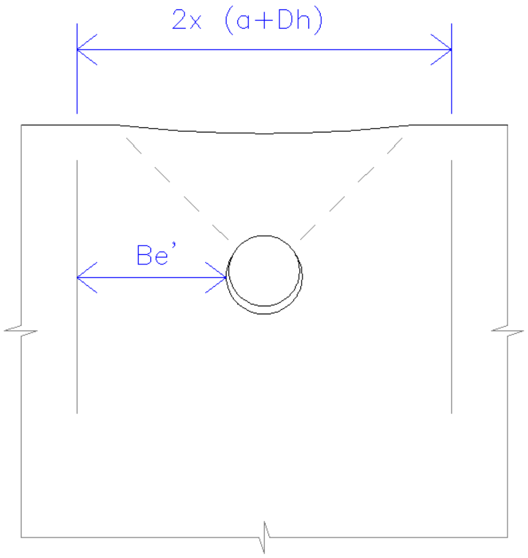
	ASME Nd=1* Fracture Estimate	ASME Nd = 1* Shear Estimate	ASME Nd=1* Tension Estimate**	Johnston Dishing Estimate	Modified Dishing Estimate***	Pincus / Duerr Inelastic Estimate	Pincus / Duerr Elastic Estimate		**Recorded Strength**
T2	90,500	83,800	30,400	57,600	30,800	-40,000	9,400		**46,000**

Units in inches pounds and degrees

* Design factor set to 1 and 1.2 data scatter multiplier removed

** Effective width set equal to 4 times the total combined thickness of the plates

*** Johnston's equation with Be' set to ((2x (a + Dh)) - Dh)/2



Test Results

- Summary of Ultimate Strengths
  - 6 degree side load without doubler plate initiated dishing and reduced strength by roughly 20% (T2 specimen)

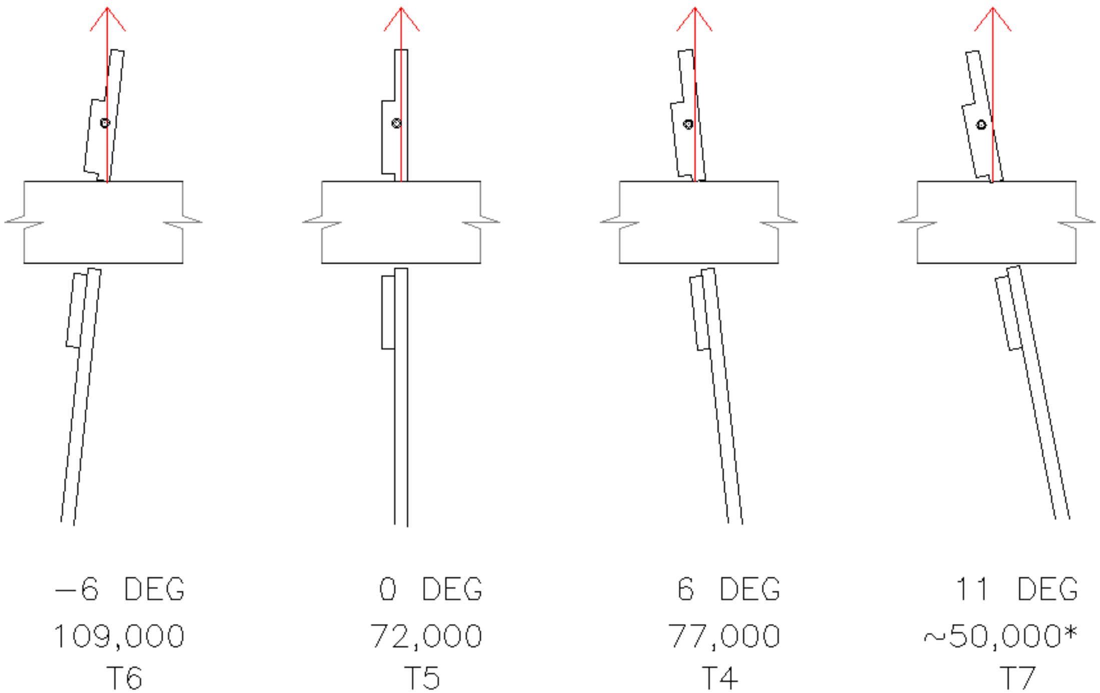
Dh = 2.31" Dp = 2.25" t = 0.25" be = 17.95" a = 3.59"

	Doubler	Thickness	a / t	Angle	Ultimate Strength	Failure Mode
T1	none	n/a	14.24	6	36,000	DS
T2	none	n/a	14.24	0	46,000	DS
T4	round	0.25	7.11	6	77,000	DS
T5	round	0.25	7.11	0	72,000	DS
T6	round	0.25	7.11	-6	109,000	DS
T7	round	0.25	7.11	11	*50,000	DF*
T9	square	0.25	7.11	6	68,000	DS
T10	rectangular no weld	0.25	7.11	6	89,000	DS
T3	round	0.50	4.74	6	165,000	DS
T8	round	0.50	4.74	0	195,000	DS**

Units in inches pounds and degrees

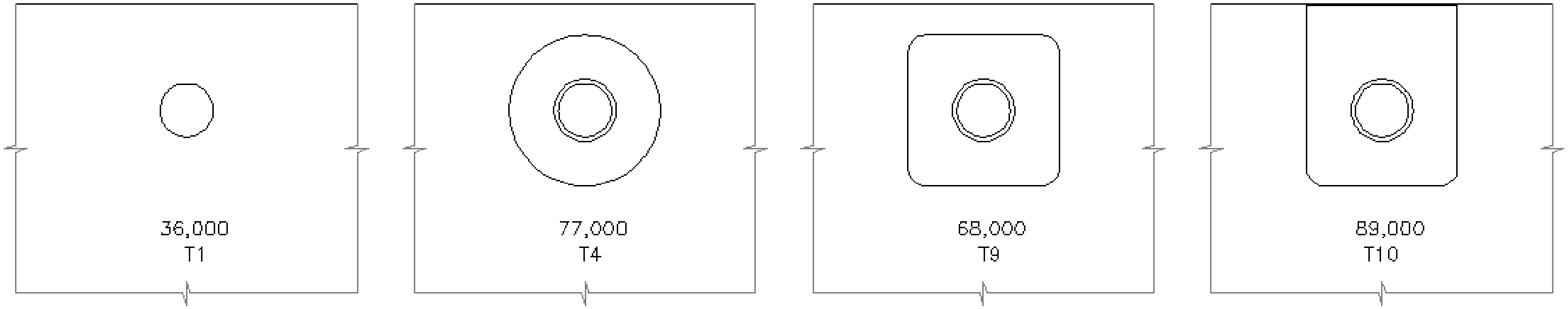
Test Results

- Side loads on “standard” boss plate
  - Force line of action compared to centroid of area can explain strength increase at -6 degrees.
  - Extreme deflection caused 11 degree sample to dish heavily and contact test frame at 50,000 lbs of load.



Test Results

- Which was the most effective doubler plate?
  - Square showed no significant difference over round.
  - Rectangular doubler with no welding at the top showed definite resilience.
    - This design had the most material above the hole, and greatest section



Conclusions

- ASME Below-The-Hook pin connection equations limit strength of thin plate attachments by tension equation which effectively eliminates Dishing instability.
- Johnstons empirical equation to predict dishing for narrow plates over estimates strength for wide plates.
- Pincus's theoretical column based dishing equation published by Duerr in 2006 cannot be applied to wide plates.
- Side load causes thin plate pin connection to dish sooner
    - ~20% reduction of strength observed for 6 degrees on two out of three samples
    - ~30% reduction of strength observed for 11 degrees on one sample

Conclusions

- Integrated Lifting Lugs in wide plates can be stiffened by production friendly lap-on offset doubler plates.
  - Rectangular shape with larger section above pin connection could be best.
  - It is very likely that a thick enough doubler plate can be choosen to eliminate dishing entirely (~4t=a)
- Integrated lifting lugs with lap-on offset doublers need to be designed for loads below the general yield point, or local damage will result.

Thank You